Comparative Study between Computer Simulated Stress and Measured Pressure Inside Internal Combustion Engine

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***Abstract*— Computer simulation for stress inside the cylinder of internal combustion engine was conducted using ANSYS 11 program and pressure inside the cylinder due to gas expansion was measured. Cylinder with piston inside was modeled in the program, element type and material model of each were defined and then they were meshed. Constraint was applied to cylinder and non-linear solution was adopted where large displacement static solution criterion was selected. Calculation control, result processing were accomplished and Von-Mises stress distribution (Equivalent stress), stresses in X, Y, and Z directions and shear stresses in X-Y, Y-Z and X-Z planes and nodal displacement were animated and recoded. Maximum and minimum vonMises stress values were 1710 kPa and 0.402 kPa respectively. Maximum normal stress was 441.5 kPa and it was recorded in X direction while the minimum normal stress was 268.3 kPa and it was recorded in Z direction (direction of piston motion). Pressure inside the cylinders of two cars namely, Hyundai Accent and Toyota 3 Y engines was measured, It was found that in case of Hyundai engine the mean pressure was 1497.9 kPa and it showed a variation of 12.4 % from simulated von-Mises stress while in case of Toyota 3 Y was 1289.3 kPa and the variation from simulated von-Mises stress was 24.6 %. It was concluded that the simulated stress was higher than pressure values inside the engine cylinder**

***Keywords*— engine computer simulation, measured pressure, simulated stress**

1. Introduction

The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) as well as of integral equations [1], [2]. The Finite Element Method is a good choice for solving partial differential equations over complicated domains [16]. Modern usage of the term "computer simulation" may encompass virtually any computer-based representation [3]. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing and training. Training simulators include flight simulators for training aircraft pilots to provide them with a lifelike experience [4], [5]. A computer simulation is a computer program that contains a model of a particular system (either actual or theoretical) and that can be executed, after which the execution output can be analyzed. Computer simulation provides tools for scientific inquiry [6], [7], [8] and problem solving experiences [9]. Reference [10] described three non-computer simulations of physical processes he then contrasted these examples with a computer simulation. Reference [11] stated that computer simulations are potentially useful for simulating labs that are impractical, expensive, impossible, or too dangerous to run. Reference [12] indicated the development of discrete-event simulation methodology of the evolution of various simulation programs. Reference [13] indicated simulink capabilities to model an internal combustion engine. Reference [14] reported an algorithm for simulation of deforming bodies, calculating there deformation and generating impulse force. Reference [15] investigated the performance characteristics of a turbocharged diesel engine using a new developed thermodynamic numerical simulation model

2. Materials and Methods

2.1 Materials

Materials used in the study include ANSYS software, internal combustion cylinder pressure tester and two cars with specifications shown in Table 1

TABLE (1). CARS SPECIFICATIONS

Car model	Specification
Accent Hyundai	Benzene, 4 stroke cycle, 8 cm bore
Toyota 3Y	Benzene, 4 stroke cycle, 9 cm bore

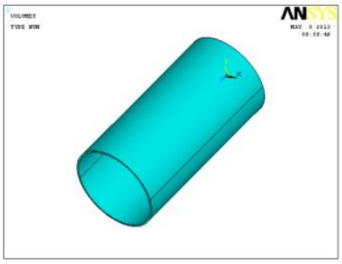

Fig.1. Model of piston and pin

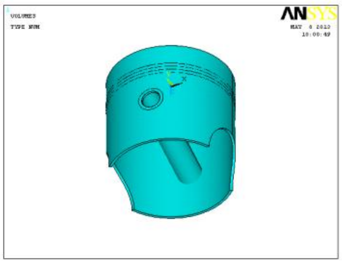

Fig. 2. Model of cylinder liner

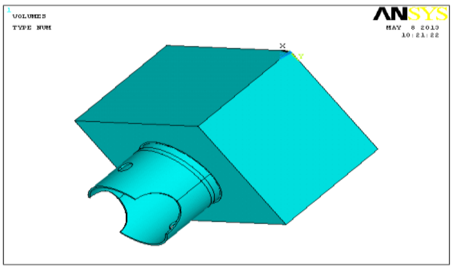

Fig. 3 Model of cylinder block and piston

2.2. Methodology

2.2.1 Structural Analysis in ANSYS

Cylinder block, pistons and cylinder liner were designed in ANSYS 11 with dimensions shown in Fig. below.

2.2.2 Material Definitions for Mesh Generation

TABLE (2) MATERIALS DEFINITION

Component	Element type	Material property		
		Material model	EX (GPa)	PRXY
Cylinder block	Solid Tet 10 node 187	Linear, Elastic, Isotropic	200e9	0.3
Piston	Solid Tet 10 node 187	Linear, Elastic, Isotropic	075e9	0.3
Cylinder liner	Solid Tet 10 node 187	Linear, Elastic, Isotropic	175e9	0.3

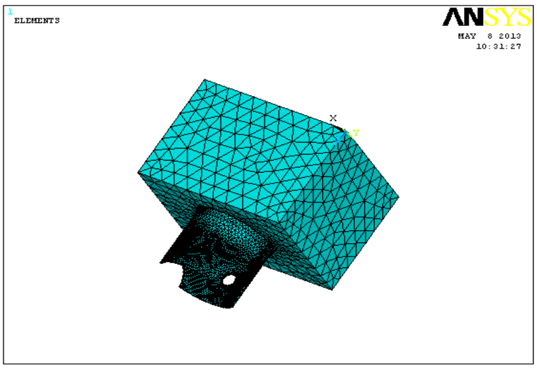

Fig. 4. Model mesh generation cylinder block and piston

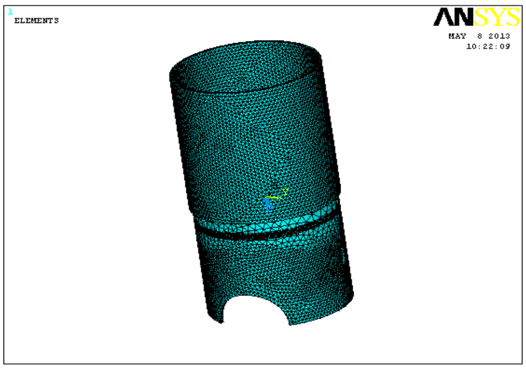

Fig. 5. Model mesh generation for cylinder liner and piston

2.2.2.1 Boundary Conditions

Piston was modeled inside the cylinder block Fig. 4, the cylinder block was constrained at 2 sides while the upper and lower sides were left unconstrained. For constraint the displacements in directions of axes were as follow

$$UX_i = 0 \quad (1)$$

$$UY_i = 0 \quad (2)$$

$$UZ_i = 0 \quad (3)$$

Next, the piston was modeled inside free cylinder liner and the liner was then constrained around its outer surface (Fig.5). Displacements in directions of axes were as follow

$UX_i = 0$……………………………..………………4

$UY_i = 0$………………………………………………5

$UZ_i = 10$…………………………………………….6

***2.2.2.2 Solution of the Boundary Problem*:**

The reactions between the piston and cylinder and between piston and liner are non-linear problems. The contact unit was established. ANSYS program was programmed for predicting the contact and the separation of the piston and cylinder and liner walls automatically. The analysis was conducted by adopting the surface-surface contacting (TARG 170 and CONTA 174). The solution criterion was selected as large displacement static.

2.2.2.3 Post-processing

Calculation control, result processing were accomplished within POST1. Von-Mises stress distribution (Equivalent stress), stresses in X, Y, and Z directions and shear stresses in X-Y, Y-Z and X-Z planes and nodal displacement were animated and recoded.

3.2.3 Experimental Work

The experiments conducted in the internal combustion engines work shop of University of kordofan, faculty of engineering and technical studies using gas cylinder compression tester shown in Fig. 6.

Fig.6 Gas cylinder compression tester

3.2.4. Pre-testing preparations

Before test was carried out the following listed preparation steps were conducted. Engine was operated for 10 minutes until the motor reaches temperature of normal operation. The spark plugs were disconnected from the cylinder After the spark plug was disconnected, the dirt was removed from the hole. The high–tension wires were displaced from the center of the distributor and they were situated in a ground Air filter was removed then throttle plate was fitted. An appropriate adapter was selected and attached to the head of pressure tester to reach the hole easily and connected to the head of the gauge [15-16].

3.2.5 Testing

Cars with specifications in Table 1 were tested to measure the pressure inside the cylinders.

The coupling's head of air gauge assembly was connected, and then the pipe in the rubber hose was screwed into the spark plug hole. The engine was operated for four strokes then was stopped and the reading of air gauge was recorded for each cylinder. A little amount of oil was added to plug opening and the test was repeated and the pressure values were recorded.

3. Results and Discussion

The simulated stresses were demonstrated in Tables 3, Figure 7, Figure 8, Figure 9 and Figure 10 while the experimental results for pressure inside the cylinders of two cars and Table 4 and Table 5.

TABLE 3. VON-MISES AND NORMAL STRESSES FOR PISTON AND CYLINDER BLOCK.

Von-mises and directions	Max. stress (kPa)	Min. stress (kPa)
Von mises	1710.00	0.402
X	0441.49	-2010.00
Y	0373.74	-1520.00
Z	0268.26	-759.75

TABLE 4. MEASURED PRESSURES INSIDE CYLINDERS OF HYUNDAI ACCENT ENGINE AND SIMULATED STRESSES.

Cylinders	Measured pressure (before oil addition) (kPa)	Measured pressure (after oil addition) (kPa)	Simulated stresses (kPa)	Δ_{before} %	Δ_{after} %
1	1516.9	1516.9	1710	11.3	11.3
2	1523.7	1523.7	1710	10.9	10.9
3	1503.1	1503.1	1710	12.1	12.1
4	1377.9	1447.9	1710	19.4	15.3
Average	1480.4	1497.9	1710.0	13.4	12.4

TABLE 5. MEASURED PRESSURES INSIDE CYLINDERS OF TOYOTA 3 Y ENGINE AND SIMULATED STRESSES.

Cylinders	Measured pressure (before oil addition) (kPa)	Measured pressure (after oil addition) (kPa)	Simulated stresses (kPa)	Δ_{before} %	Δ_{after} %
1	1267.55	1310.00	1710.00	25.9	23.4
2	1284.79	1323.79	1710.00	24.9	22.6
3	1351.29	1351.37	1710.00	21.0	21.0
4	1108.21	1172.11	1710.00	35.2	31.5
Average	1253.0	1289.3	1710.0	26.8	24.6

3.2 Discussion

3.2.1 Simulation

3.2.1.1 Von-mises and Normal Stresses Distribution

As shown in Table 3, the maximum value of Von-mises stress for piston with cylinder block is 1710 k Pa while the minimum value is 0.402 k Pa. Maximum value of normal stresses in X, Y and Z axes were 441.49 k Pa, 268.74 k Pa and 373.26 k Pa respectively while the minimum values are -2010 k Pa in X axis, -1520 k Pa in Y axis and -759.75 k Pa and the negative sign indicates that the stresses are compressive stresses. Von-mises stress recorded the highest values as compared to normal stresses.

3.2.2 Measured Cylinder Pressure Compared to Simulated Stress

Table 4 showed that the value of measured pressure inside cylinders of Hyundai Accent engine before adding oil in cylinder 1 was 1516.86 KPa with variation of 11.3 % from simulated stress and after adding oil was 1516.85 KPa with 11.3 % deviation from simulated stress which was 1710 KPa. In cylinder 2, measured pressure before and after adding oil was 1523.74 KPa with variation of 10.9 % from simulated stress. In cylinder 3, measured pressure before and after adding oil was 1503.07 KPa with variation of 12.1 % from simulated stress, while in cylinder 4 the values of measured pressure before and after addition of oil were 1377.93 KPa and 1447.89 KPa with deviations from simulated stress of 19.4 % and 15.3 % respectively. It was found that the highest measured pressure was recorded by cylinder 2 while the lowest pressure was shown by cylinder 4 therefore, it can be concluded that cylinder 2 has the highest compression process while cylinder 4 has the lowest compression process. The mean pressure for 4 cylinders was 1480.4 kPa before adding oil with mean deviation of 13.4 % from simulated stress (von-Mises) and 1497.9 kPa after adding oil with mean deviation of 12.4 % from simulated stress. When considering values of measured pressure before and after addition of oil, there was no change in the values before and after adding oil in cylinder 1, cylinder 2, and cylinder 3 which indicates that the valves are not closed tightly, in cylinder 4 the value of measured pressure was increased after adding oil which indicates that there was some damage in pressure rings.

In case of Toyota 3Y engine as shown in Table 5, the value of measured pressure before adding oil in cylinder 1 was 1267.55 KPa with variation of 25.9 % from simulated stress and after adding oil was 1310 KPa with 23.4 % deviation from simulated stress which was 1710 KPa. In cylinder 2, values of measured pressure before and after adding oil were 1284.79 KPa and 1323.79 KPa with deviations from simulated stress of 24.9 % and 22.6 % respectively. In cylinder 3, measured pressure before and after adding oil was 1351.37 KPa with variation of 21 % from simulated stress, while in cylinder 4 the values of measured pressure before and after addition of oil were 1108.21 KPa and 1172.11 KPa with deviations from simulated stress of 35.2 % and 31.5 % respectively. It was found that the highest measured pressure was recorded by cylinder 3 while the lowest pressure was shown by cylinder 4, therefore, it can be concluded that cylinder 3 has the highest compression process while cylinder 4 has the lowest compression process. The mean pressure for 4 cylinders was 1235.0 kPa before adding oil with mean deviation of 26.8 % from simulated stress (von-Mises) and 1289.3 kPa after adding oil with mean deviation of 24.6 % from simulated stress. When considering values of measured pressure before and after addition of oil, there was no change in the values before and after adding oil in cylinder 3 which indicates that the valves are not closed properly, in cylinder 1, cylinder 2 and cylinder 4 the values of measured pressure was increased after adding oil which indicates that there was some damage in pressure rings.

In both cases of Hyundai and Toyota the recorded experimental values of pressure are less than simulated Von-mises stress values, and pressure values in Hyundai cylinders are highest than in Toyota cylinders, consequently, the variations between measured pressure and simulated stress are lowest in case of Hyundai as compared to Toyota. Even within the cylinders of same car there are considerable variations were noticed, accordingly, some repair and maintenance were required either to change some pressure rings or to close the valves firmly so as to increase the pressure inside the cylinders.

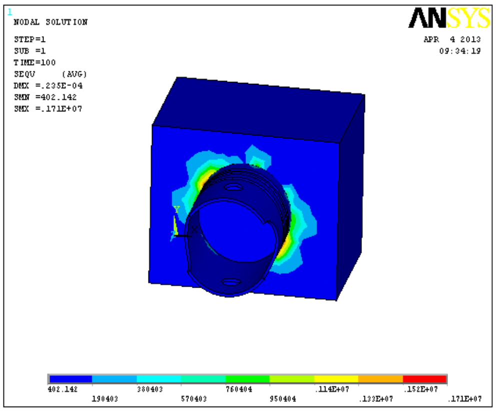

Fig. 7 Von-Mises Stress distribution

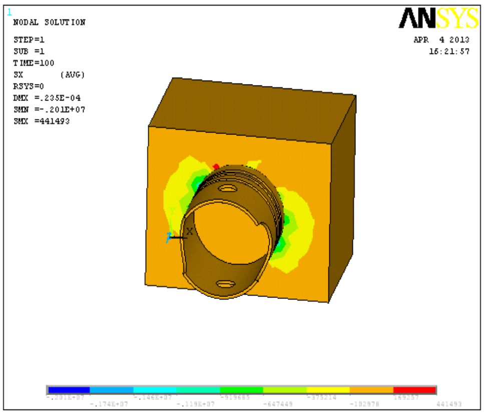

Fig. 8 Normal Stress distribution in X axis

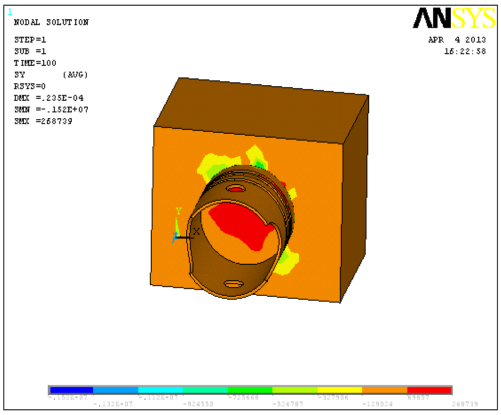

Fig. 9 Normal Stress distribution in Y axis

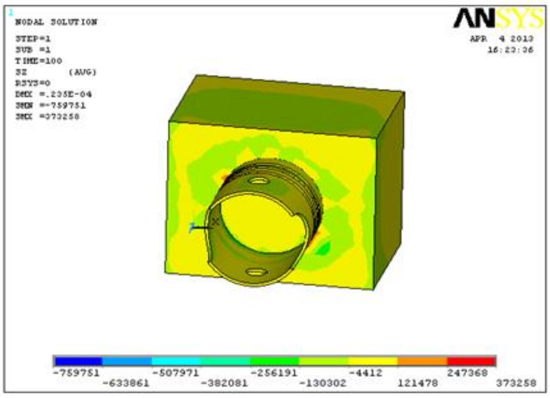

Fig. 10 Normal Stress distribution in Z axis

Conclusion

Computer simulation was conducted using a finite element method program (ANSYS 11) to investigate the stresses distribution in some engine elements such as piston, cylinder block and cylinder liner. Experimental work was done to determine the pressure values inside cylinders of two vehicles namely Hyundai Accent and Toyota 3 Y. Computer simulated stress was compared to experimental pressure and it was found that the simulated stress values was higher than pressure. It was concluded that there was some repair and maintenance were needed for both vehicles. Computer simulation technique is an effective tool for conducting the processes at virtual level before been implemented so as to minimize cost, efforts and resources.

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